Central University of Himachal Pradesh

Department of Physics and Astronomical Science

Department Model Curriculum for M. Sc. Physics Programme

2017

Semester-Wise Distribution of Courses:

Semester	Core Courses		Elective Courses		Foundation Courses		Total Credits
	Compulsory	Open	Specialization	Open	Skill Development	Human Making	
I	CC-I (4) CC-II (4) CC-III (4) CC-X (2)	CO-I (2)	--	--	SD-I (2)	HM-I (2)	**20**
II	CC-IV (4) CC-V (4)	CO-II (2) CO-III (2) CO-IV (2) CO-V (2)	--	--	SD-II (2)	HM-II (2)	**20**
III	CC-VI (4) CC-VII (4) CC-VIII (4) CC-XI (2)	--	ES-I (4)	EO-I (2)	--	--	**20**
IV	CC-IX (4)	CO-VI (2)	ES-II (4) ES-III (4) ES-IV/Project (4)	EO-II (2)	--	--	**20**
Total	**40**	**12**	**16**	**4**	**4**	**4**	**80**

Core-Compulsory (CC) Courses:

C. No	Course Code	Course Name	Course Credit
CC-I	PAS 401A	Classical Mechanics	4
CC-II	PAS 403A	Electro-dynamics	4
CC-III	PAS 404A	Quantum Mechanics	4
CC-IV	PAS 406A	Statistical Mechanics	4
CC-V	PAS 407A	Advanced Quantum Mechanics	4
CC-VI	PAS 408A	Condensed Matter Physics	4
CC-VII	PAS 409A	Nuclear and Particle Physics	4
CC-VIII	PAS 411A	Atomic, Molecular and Laser Physics	4
CC-IX	PAS 428A	Computational Physics	4
CC-X	PAS 413	General Physics Laboratory	2
CC-XI	PAS 423	Modern Physics Laboratory	2

Core-Open (CO) Courses:

S. No	Course Code	Course Name	Course Credit
1	PAS 402	Mathematical Physics	2
2	PAS 414	Computer Simulations in Physics	2
3	PAS 427	Computational Physics Laboratory	2
4	PAS 528	Accelerator and Reactor Physics	2
5	PAS 529	Group Theoretical Physics	2
6	PAS 412	Semiconductor Devices	2
7	PAS 506	General Theory of Relativity	2
8	PAS 405	Electronic Circuits	2
9	PAS 415	Electronics Lab	2

Elective Open (EO) Courses:

S. No	Course Code	Course Name	Course Credit
1	PAS 516	Nano-materials and Technology	2
2	PAS 518	Opto-electronics	2
3	PAS 539	Cosmology	2
4	CSI 411	Modeling and Simulation	2
5	PAS 545	Unitary Symmetries in Quantum Physics	2

Elective Specialization (ES) Courses:

S. No	Course Code	Course Name	Course Credit
1	PAS 426A	Quantum Field Theory	4
2	PAS 527	Theoretical Nuclear Physics	4
3	PAS 549	Elementary particles and Interactions	4
4	PAS 506A	Theory of General Relativity	4
5	PAS 546A	Neutrino Physics	4
6	PAS 552	Molecular Simulations in Material Science	4
7	PAS 528A	Particle Accelerators, Detectors and Reactors	4
8	PAS 613	Characterization of Materials	4

Skill Development (SD) Courses:

S. No	Course Code	Course Name	Course Credit
1	PAS 427A	Scientific Writing and Presentation	2
2	PAS 556	Science of Yoga	2

Human-Making (HM) Courses:

S. No	Course Code	Course Name	Course Credit
1	PAS 417A	History and Philosophy of Science	2
2	PAS 556	Science of Yoga	2

Core Compulsory Courses

Classical Mechanics

Course Code: PAS 401A **Course Type: Core Compulsory**
Course Credits: 4

Course Objectives:

Understanding the concepts of classical mechanics which serves as a springboard for the various branches of modern physics; Lagrangian and Hamiltonian formulations of the dynamical systems; Hamilton Jacobi theory and the principle of least action provide the transition to wave mechanics while Poisson brackets and canonical transformations are invaluable in formulating the quantum mechanics.

Course Contents

Unit 1: Constrained motion and Lagrangian formulation: (8 hours)

- Newtonian mechanics: brief review and limitations.
- Constraints and their classification with examples, principle of virtual work.
- D'Alembert's principle, degrees of freedom, generalised coordinates.
- Lagrange's equation from D'Alembert's principle.
- Lagrangian for various simple mechanical systems such as simple pendulum, Atwood machine, spherical pendulum.
- Charged particle in an electromagnetic field etc., invariance of Euler-Lagrange equations of motion under generalized coordinate transformations.
- Cyclic or ignorable coordinates integrals of motion.
- Concept of symmetry: homogeneity and isotropy, Lagrange’s equations of motion for non-holonomic systems.

Unit 2: Rotating frame of reference and Central force problem: (8 hours)

- Inertial forces in rotating frame.
- Coriolis force and its effects.
- Reduction to the equivalent one-body problem.
- Stability of orbits, conditions for closure.
- Virial theorem.
- Kepler problem: inverse square law force.
- Scattering in a conservative central force field.

Unit 3: Hamilton's equation of motion, Principle of least action and Hamilton principle: (6 hours)

- Legendre transformations, Hamilton’s function and Hamilton's equation of motion.
- Routhian, Configuration and phase space.
- Principle of least action, Hamilton’s principle.
- Derivation of E-L equations of motion from Hamilton’s principle, Derivation of Hamilton’s equations of motion for holonomic systems from Hamilton’s principle.

- Invariance of Hamilton’s principle under generalized coordinate transformation.
- Lorentz invariance of Hamilton’s principle functions for the relativistic motion of a free particle.

Unit 4: Canonical transformations: (5 hours)

- Equations of canonical transformation (CT), generating functions.
- Properties and examples of canonical transformations.
- Liouville’s theorem, Area conservation property of Hamiltonian flows.
- Poisson brackets (PB), Poisson’s theorem.
- Invariance of PB under CT, angular momentum Poisson brackets

Unit 5: Theory of Small Oscillations: (3 hours)

- Coupled coordinates, expansion about static equilibrium.
- Normal modes, Two coupled pendulum.
- Linear triatomic molecule.

Unit 6: Hamilton Jacobi theory: (5 hours)

- Hamilton Jacobi (HJ) equation.
- Time dependent HJ equation and Jacobi theorem
- Harmonic oscillator problem as an example of the Hamilton Jacobi method.
- Action angle variables and examples.

Unit 7: Rigid body dynamics: (5 hours)

- Degree of freedom of a free rigid body.
- Euler’s and Chasle’s theorem
- Euler's equation of motion for rigid body
- Motion of a heavy symmetric top rotating about a fixed point in the body under the action of gravity precession and nutation.

Prescribed Textbooks:

1. Classical Mechanics, H. Goldstein.
2. Classical Mechanics, N. C. Rana and P. S. Joag, Tata McGraw-Hill.

Other Resources/Reference books:

1. Mechanics, L. D. Landau and E. M. Lifshitz.
2. Classical dynamics of particles and systems, J. Marion and S. Thornton, Brooks- Cole.
3. Analytical Mechanics, Louis N. Hand and Janet D. Finch, Cambridge University Press.
4. Classical mechanics for physics graduate students, Ernesto Corinaldesi, World Scientific publishing.
5. Introduction to classical mechanics: with problems and solutions, David Morin, Cambridge University Press.

Classical Electrodynamics

Course Code: PAS– 403A **Course Type: Core-Compulsory**
Course Credit: 4

Course Objectives:

Maxwell's theory of electromagnetic phenomenon is a basic component of all modern courses of theoretical physics and all students of physics must have a thorough knowledge of its principles and working. The basic ingredient of this theory is the concept of a field and the equations which govern the space and time evolution of these fields. These fields are called electromagnetic fields and the equations are known as the Maxwell equations. Moreover, these fields show a wave behavior and are termed as electromagnetic waves. Visible light is an example of electromagnetic wave. In this course, we shall learn about the working and applications of the Maxwell equations and how it is consistent with the theory of relativity.

Course Contents

Unit 1: Mathematical preliminaries **(4 hours)**

- Vector analysis: differentiation and integration.
- Dirac's delta function: representation and use.

Unit 2: Electrostatics and Magnetostatics **(6 hours)**

- Scalar and vector potentials.
- Multiple expansion of
  - Scalar potential due to a static charge distribution.
  - Vector potential due to a stationary current distribution.

Unit 3: Maxwell's theory and conservation laws **(4 hours)**

- Maxwell's equations; charge, energy and momentum conservation (Poynting’s vector and Maxwell’s stress tensor)
- Electromagnetic fields and wave solution.

Unit 4: Radiation from time-dependent sources of charges and currents **(6 hours)**

- Inhomogeneous wave equations and their solutions;
- Radiation from localised sources and multipole expansion in the radiation zone.

Unit 5: Radiation from moving point charges **(10 hours)**

- Lienard-Wiechert potentials;
- Fields due to a charge moving with uniform velocity;
- Fields due to an accelerated charge;
- Radiation at low velocity; Larmor’s formula and its relativistic generalisation;

- Radiation when velocity (relativistic) and acceleration are parallel, Bremsstrahlung;
- Radiation when velocity and acceleration are perpendicular, Synchrotron radiation;
- Cherenkov radiation ;
- Radiation reaction, Problem with Abraham-Lorentz formula
- Limitations of classical theory.

Unit 6: Relativistic formulation of electrodynamics (10 hours)

- Introduction to special relativity: Postulates of Einstein,
- Geometry of relativity, Lorentz transformations.
- Relativistic mechanics: Proper time, proper velocity, Kinematics and dynamics.
- Four vector notation
- Electromagnetic field tensor, covariance of Maxwell's equations.

Prescribed Textbooks:

1. D. J. Griffiths: Introduction to electrodynamics, Prentice Hall.
2. W. Panofsky and M. Phillips: Classical electricity and magnetism, Addison Wesley.

Other Resources/Reference books:

1 J. Marion and M. Heald: Classical electromagnetic radiation, Saunders college publishing.
2 L. Landau and E. Lifshitz: Classical theory of fields, Pergamon Press.
3 J. Jackson: Classical electrodynamics, Wiley international.
4 M. Schwartz: Classical electromagnetic theory, Dover publication

Quantum Mechanics

Course Code:PAS 404 A **Course Type: Core Compulsory**
Credits: 4

Course Objectives:

The purpose of the course is to provide a comprehensive introduction and application of the quantum mechanics and develop pre-requisite for the next course 'Advanced Quantum Mechanics'. Starting from Fundamentals of Quantum Mechanics, Mathematical Formalism, Representation Theory, Eigenfunctions, Eigenvalues, Unitary Matrix, Schrodinger and Heisenberg representations; Energy Eigenvalue Problems; Matrix Representations, Angular Momentum Operators and Addition of Angular Momenta, Time Independent Perturbation Theory, Variational Principle and WKB Method.

Course Contents

Unit 1: Fundamentals of Quantum Physics **(10 hours)**

- Schrodinger's equation, Statistical interpretation of the wave function and normalisation
- Expectation values of operators, Ehrenfest's theorems
- Stationary solutions. Normalisable and non- normalizable states
- Eigenvalues and eigenfunctions, orthornormality and completeness of solutions
- Simple one- dimensional potentials: Square- well and delta function
- Free particle: Non-normalisable solutions, wave packets, box normalisation
- Momentum space representations, Perseval's theorem.

Unit 2: Mathematical Foundations **(8 hours)**

- Finite dimensional linear vector space and inner product spaces
- Dual spaces and the Dirac notation of bra and ket
- Linear transformations (operators) and their matrix representations
- Hermitian and unitary operators and their properties
- Generalisation to infinite dimensions
- Incompatible observables, Uncertainty relation for two arbitrary operators and it's proof.

Unit 3: Quantum dynamics **(4 hours)**

- Schroedinger picture: Unitary time evolution, Schrodinger equation
- Heisenberg picture: Heisenberg operators, Heisenberg's equation of motion
- Linear Harmonic Oscillator by operator method and it's time evolution.

Unit 4: Three dimensional problems **(4 hours)**

- Three dimensional problems in Cartesian and spherical coordinates
- Square wells and harmonic oscillator
- Hydrogen atom, Radial equation and it's solution.

Unit 5: Angular Momentum **(4 hours)**

- Angular Momentum Operators and their algebra
- Eigenvalues and Eigenfunctions
- Matrix representations for different j

- Spin Angular Momentum and Addition of Angular Momenta
- Clebsch-Gordan Coefficients.

Unit 6: Time Independent Perturbation Theory **(6 hours)**

- Basic Concepts, Non-degenerate Energy Levels
- First and Second Order Corrections to the Wave function and Energy
- Degenerate Perturbation Theory
- Relativistic correction and Spin-orbit Interactions
- Zeeman Effect and Stark Effect.

Unit 7: The Variation Method and WKB Approximation **(4 hours)**

- The Variation Principle, Rayleigh-Ritz Method
- Variation Method for Excited States
- Ground State of Helium
- WKB Method, Connection Formula
- Validity of WKB Method
- Tunnelling through a Barrier and alpha decay.

Prescribed Textbooks:

1. **G. Aruldhas,** Quantum Mechanics, PHI Learning, Eastern Economy Edition 2013.
2. **W. Greiner,** Quantum Mechanics-An Introduction, Springer-Verlag, Germany.
3. **David J. Griffiths,** Introduction to Quantum Mechanics, Pearson Prentice Hall, Inc.

Other Resources/Reference books:

1. **Ashok Das,** Quantum Mechanics, Tata McGraw Hill (2007).
2. **Leonard. I. Schiff,** Quantum Mechanics, 3rd edition, Tata McGraw-Hill 2010.
3. **J.J. Sakurai,** *Modern Quantum Mechanics*, Addison-Wesley ISBN 0-201-06710-2).
4. **R. Shankar,** Principles of Quantum Mechanics, Second edition, Plenum Press, New York.
5. **E. Marzbacher,** Quantum Mechanics, Wiley Student Edition, 2011.
6. **Mathews and Venkateshan**, Quantum Mechanics, Tata McGraw-Hill 2010.
7. **P.A.M. Dirac**, The Principles of Quantum Mechanics, Snowball Publishing.
8. **A. Messiah**, Quantum Mechanics, Dover Books on Physics.

Statistical Mechanics

Course Code: PAS 406A **Course Type: Core Compulsory**
Course Credits: 4

Course Objectives:

Connection between Thermodynamics and Statistical Mechanics, Develop statistical mechanics techniques such as ensemble theory and their application to ideal and real systems. Theory of Phase transition.

Course Contents

Unit-1: Classical Statistical Mechanics (5 hours)

- Foundation of statistical mechanics.
- Specification of state of a system
- Contact between statistics and thermodynamic.
- Classical ideal gas, entropy of mixing
- Sackur-tetrode equation and Gibb's paradox.

Unit-2: Ensemble Theory: Microcanonical, Canonical Ensemble (6 hours)

- Phase space, phase-space trajectories and density of states
- Liouville theorem
- Microcanonical ensemble: Classical Ideal gas.
- Canonical ensemble: canonical partition function(CPF, average energy in canonical ensemble,)
- Relation between CPF and Helmholtz free energy
- Equivalence of canonical and microcanonical ensembles.

Unit-3: Ensemble Theory: Grand Canonical Ensemble (5 hours)

- Factorization of Canonical Partition function: Classical ideal gas
- Maxwell velocity distribution, Equipartition theorem
- Grand canonical ensemble: Partition function
- Calculation of statistical quantities, particle density and energy fluctuations.

Unit-4: Quantum Statistical Mechanics: Statistical Distributions (6 hours)

- Density matrix, statistics of ensembles.
- statistics of indistinguishable particle.
- Harmonic oscillator at temperature T, Maxwell-Boltzmann
- Fermi-Dirac and Bose-Einstein statistics: in microcanonical and grand canonical ensemble

Unit-5: Quantum Gases (7 hours)

- Ideal quantum gases: Bose gas, Fermi gas equation of state, energy density
- Standard functions, non-degenerate case
- Degenerate Fermi gas, Sommerfeld expansion: chemical potential and specific heat of degenerate Fermi gas
- Pauli paramagnetism: low and high temperatures

- Bose-Einstein condensation: Pressure and specific heat.

Unit-6: Approximate Methods and Ising Model **(7 hours)**

- Cluster expansion for a classical real gas
- Virial equation of state
- Ising model, mean field theories of the Ising model in three, two and one dimensions
- Exact solutions in one-dimension.

Unit-7: Theory of Phase transition **(4 hours)**

- Landau theory of phase transition
- Critical indices
- Scale transformation and dimensional analysis.

Prescribed Text Books:

1. Statistical Mechanics, Kerson Huang, Wiley
2. Statistical Mechanics, R. K. Pathria and Paul D. Beale, Elsevier.

Other Resources/Reference books:

1. Statistical and Thermal Physics, F. Reif.
2. Statistical Physics, Landau and Lifshitz.
3. Statistical Mechanics, R. Kubo.

Advanced Quantum Mechanics

Course Code: **PAS 407A** **Course Type: Core Compulsory**

Credits: **04**

Course Objectives:

This course is the next step to learn quantum mechanics, which will cover addition of Angular Momentum, Symmetries in quantum mechanics, scattering Theory, Relativistic wave equations.

Course Contents

Unit 1: Time-dependent Perturbation Theory **(10 hours)**

Time dependent perturbation theory, interaction picture; Constant and harmonic perturbations — Fermi's Golden rule; Sudden and adiabatic approximations.

Unit 2: Scattering Theory **(10 hours)**

Laboratory and centre of mass frames, differential and total scattering cross-sections, scattering amplitude; Scattering by spherically symmetric potentials; Partial wave analysis and phase shifts; Relation between sign of phase shift and attractive or repulsive nature of the potential; Scattering by a rigid sphere and square well; Coulomb scattering; Formal theory of scattering —Green's function in scattering theory; Lippman-Schwinger equation; Born approximation.

Unit 3: Symmetries in Quantum Mechanics **(8 hours)**

Conservation laws and degeneracy associated with symmetries; Continuous symmetries — space and time translations, rotations; Rotation group, homomorphism between SO(3) and SU(2); Explicit matrix representation of generators for j = 2 and j = 1; Rotation matrices; Irreducible spherical tensor operators, Wigner-Eckart theorem; Discrete symmetries — parity and time reversal; Identical particles.

Unit 4: Relativistic Quantum Mechanics **(12 hours)**

Klein-Gordon equation, interpretation of negative energy states and concept of antiparticles; Dirac equation, covariant form, adjoint equation; Plane wave solution and momentum space spinors; Spin and magnetic moment of the electron; Non-relativistic reduction; Helicity and chirality; Properties of gamma matrices; Charge conjugation; Normalisation and completeness of spinors.

Prescribed Text Books:

1. **J.J. Sakurai,** *Modern Quantum Mechanics*, **Addison-Wesley** (ISBN 0-201-06710-2).
2. **R. Shankar**, *Principles of quantum mechanics*, **Plenum Press**.
3. **D. J Griffiths,** *Introduction to Quantum Mechanics*, **Pearson Prentice Hall,** (2005).

Other Resources/ Reference Books:

1. **James D. Bjorken and Sidney D. Drell,** *Relativistic Quantum Mechanics,* McGraw-Hill Company, New York.
2. **G. Aruldhas,** *Quantum Mechanics*, PHI Learning, Eastern Economy Edition 2013.
3. **L. D. Landau and L. M. Lifshitz**, *Quantum Mechanics: Non-Relativistic Theory, Volume 3,* (Butterworth-Heinemann, 3rd edn, 1981)

Condensed Matter Physics

Course Code: PAS 408A **Course Type: Core Compulsory**
Credit: 4
Course Objectives:

The course aims to introduce students to the internal architecture of materials to explore phenomena happening in materials at atomistic length scales.

Course Contents

Unit 1: Crystal Structure and Reciprocal Lattice (10 hours)

- Review of basic concepts in crystalline solids, periodic array of atoms
- Lattice, basis and crystal structure, unit cell, primitive lattice cell crystallographic planes and Miller indices.
- Symmetry operations, the seven crystal systems and Bravais lattices, point and space groups,
- Schoenflies and International notations. Illustration of some crystals such as NaCl, CsCl, Diamond structure, HCP and honeycomb lattice, Cubic ZnS, Perovskite structure.
- Diffraction of waves by crystals, Bragg's law
- Scattered wave amplitude, Fourier analysis, Reciprocal lattice vectors, diffraction conditions Laue equations.
- Brillouin zones. Wigner-Seitz cell and Ewald's construction.
- Structure factors and atomic form factors. Quasicrystals.
- Experimental methods of crystal structure determination: Laue, rotating crystal and powder method,
- Basics of electron and neutron diffraction by crystals.

Unit 2: Crystal Binding, Elastic Constants And Atomic Vibrations (12 hours)

- Continuum model and analysis of elastic strains, Elastic compliance and stiffness constants
- Elastic waves in cubic crystals: Longitudinal and transverse waves.
- Different types of binding forces for atoms in materials, cohesive energy
- Lenard-Jones potential and crystals of inert gases
- Ionic crystals and Madelung constant,
- Covalent and metallic crystals, hydrogen bonding. Atomic and ionic radii. Bulk modulus.
- Failures of static lattice approximation. Classical theory of Harmonic crystals: Harmonic and adiabatic approximations, Specific heat
- Vibrations of 1D crystals with mono atomic basis
- di and poly atomic basis Acoustical and optical phonon branches. Vibrations in 3D lattices.

- Phonon momentum, inelastic scattering by phonons.
- Quantum theory of Harmonic crystals: low and high temperature specific heat, Einstein and Debye models for phonon heat capacity.
- Phonon density of states. Anharmonic crystal interaction, thermal expansion, thermal conductivity of phonon gas, Normal and Umklapp processes.

Unit 3: Electron Gas: Free Electron Gas And Electrons In Lattice (14 Hours)

- Brief review of Drude model, Sommerfeld theory of metals, Fermi Dirac distribution function and effect of temperature on FD distribution function
- Free electron gas in three dimensions, electronic density of states. Fermi energy, momentum.
- Heat capacity of electron gas, heavy fermions. Electrical conductivity and Ohm's law.
- Motion of electron in magnetic fields: Hall effect.
- Thermal conductivity of metals and Wiedemann Franz law.
- Failures of free electron theory, electron in periodic potential. Nearly free electron model: origin and magnitude of band gap, Bloch's theorem.
- Born-Von Karman boundary conditions. Wave equation of electrons in a periodic potential: crystal momentum, central equation
- Kronig-Pennney model in reciprocal space,
- Empty lattice approximation, approximate solution near zone boundary.
- Density of states and van-Hove singularity.
- Extended, periodic and reduced zone schemes. effective mass of electron and concept of holes
- Tight binding method
- Band structures of some materials (Cu, Si, GaAs, NaCl).
- Fermi surfaces and their determination dHvA effect.

Unit 4: Superconductivity And Magnetism (12 Hours)

- **Superconductivity:** Introduction; experimental facts, zero resistivity, critical temperature, critical B field and critical current.
- Type-I and type-II superconductors, vortex state. Basic properties of superconductors: Isotope effect, Specific heat, Meissner effect,
- Thermodynamic properties; London equations
- Basic elements of BCS theory, Flux quantisation in superconducting ring, High temperature superconductors.
- **Magnetism:** Magnetization of matter and classification of magnetic materials. Diamagnetism and Langevin theory of diamagnetism.
- Paramagnetism: Langevin theory and Curie law for Paramagnetism,
- Weiss theory of Paramagnetism and Curie-Weiss law,
- Pauli Paramagnetism. Quantum theory of Paramagnetism: Effective number of Bohr magneton, Brillouin function.

- Ferromagnetism, ferromagnetic Curie temperature, exchange interaction, mean field approximation.
- Brief idea of Heisenberg model, magnons: Bloch $\mathbf{T^{3/2}}$ law.
- Magnetic domains and domain theory, Bloch wall. Superparamagnetism.
- Ferrimagnetism: Curie temperature and Susceptibility. Antiferromagnetism: Neel temperature.

Prescribed Textbooks:

1. Introduction to Solid State Physics, C. Kittel, Wiley 8th edition
2. Solid State Physics, N. W. Ashcroft and N.D. Mermin, Cengage Learning
3. Solid State Physics, S.O. Pillai, New Age International

Other Resources/Reference Books:

1. Solid State Physics, Guiseppe Grosso and Guiseppe Pastori Parravicini, Academic Press
2. Solid State Physics, A. J. Dekker, Prentice Hall
3. Understanding solids: The science of materials, Richard J. D. Tilley, John Wiley and Sons

Nuclear and Particle Physics

Course Code:PAS 409A **Course Type: Core Compulsory**
Credits: 4
Course Objectives:

The course is designed to prepare the students for their CSIR-UGC National Eligibility Test (NET) for Junior Research Fellowship and Lecturer-ship. Basic nuclear properties like size, shape, charge distribution, spin and parity. Binding energy, semi-empirical mass formula; Liquid drop model, Nature of the nuclear force, form of nucleon-nucleon potential, Deuteron problem, Nuclear reactions, reaction mechanisms, Nuclear Models , Theories and spectra of Alpha, Beta and Gamma decays and their selection rules,
Elementary particles, C, P, and T invariance, Symmetry groups, parity nonconservation in weak interaction, Quark Model, quark model, eightfold way, four forces, quantum electrodynamics (QED), quantum chromo dynamics (QCD), weak interactions, decay and conservation laws, unification scheme.

Course Contents

Unit 1: General Properties of Nucleus **(8 hours)**

- Nuclear shapes and sizes: matter and charge distribution
- Quantum properties: parity, spin and magnetic dipole moment
- Mass spectroscopy, binding energy, Fusion and fission
- Semi-empirical mass formula: the Liquid drop model.

Unit 2: Nuclear Interaction **(8 hours)**

- Classification of fundamental forces, Nature of the nuclear forces, Qualitative aspects of nuclear force: Strength and range
- Two-body bound state problem (deuteron)
- Nucleon-nucleon scattering at low energies
- Saturation of nuclear forces and charge-independence and charge-symmetry
- Nuclear reaction mechanisms, Compound nucleus reaction, Direct nuclear reactions and heavy ion reactions.

Unit 3: Nuclear Structure **(8 hours)**

- Evidence of shell structure
- Single particle shell model its validity and limitations
- Collective Model: rotational spectra
- Theory of α-decay and α-ray spectra

- Fermi theory of β-decay and selection rules, conditions for spontaneous emission, continuous β-ray spectrum and neutrino hypothesis

- Theory of γ-decays and selection rules.

Unit 4: Introduction to the Elementary particles (8 hours)

- Classification and properties of elementary particles and their interactions, quarks, leptons, Spin and parity assignments, iso-spin, strangeness
- Gell-Mann-Nishijima formula
- Quantum numbers and their conservation laws
- Quark model , eightfold way.

Unit 5: Elementary particles dynamics (8 hours)

- C, P, and T invariance and applications of symmetry arguments to particle reactions
- parity non-conservation in weak interaction
- Symmetry Groups-SU(2), SU(3), four forces, weak interactions, decay and conservation laws, unification scheme.

Prescribed Textbooks:

1. K.S. Krane: Introductory Nuclear Physics, John Wiley& Sons Ltd.
2. D. Griffiths: Introduction to Elementary particles, John Wiley & Sons, 1987.

Other Resources/Reference books:

1. B.R. Martin: Nuclear and Particle Physics, John Wiley & Sons Ltd.
2. H.A. Enge: Introduction to Nuclear Physics, Addison-Wesley (1971).
3. V.K. Mittel, R.C. Verma and S.C. Gupta: Nuclear & Particle Physics, PHD.
4. D.C. Tayal: Nuclear Physics, Himalaya Publishing House Pvt. Ltd (2008).
5. M.P. Khanna: Particle Physics, PHD.

Atomic, Molecular and Laser Physics

Course Code: PAS 411A **Course Type: Core Compulsory Course**
Credit:4
Course Objectives:

The course is designed to, discuss various aspects of atomic, and molecular spectra, Understand about Lasers and their applications to non-linear optics

Course Contents

Unit 1: Interaction of Radiation with Matter (4 hours)

- Electromagnetic spectrum, Spectrometers and experimental considerations
- Classical and Quantum Mechanical explanation of Micro-wave, IR and Raman Spectroscopy
- Time-dependent perturbation theory of radiation-matter interations
- Selection rules for one-photon transitions

Unit 2: Atomic Spectra (6 hours)

- Hydrogenlike Spectra, Spin—Orbit Coupling
- Variational Principle, Hamiltonian for many electron system and Born-Oppenheimer Approximation
- Hartree Theory for He atom
- Hartree-Fock method for excited state of He atom
- Angular Momentum Coupling in Many-Electron Atoms
- Many-Electron Atoms: Selection Rules and Spectra
- The Zeeman Effect

Unit 3: Rotation and Vibrational Spectra in Diatomics (5 hours)

- Diatomic Rotational Energy Levels and Spectroscopy
- Vibrational Spectroscopy in Diatomics
- Vibration—Rotation Spectra in Diatomics
- Centrifugal Distortion
- The Anharmonic Oscillator

Unit 4: Electronic Spectra in Diatomics (5 hours)

- LCAO—MO Wave Functions in Diatomics
- Molecular Orbital Theory of Hydrogen molecule
- Electronic Spectra in Diatomics
- Flouroscence Spectroscopy
- NMR and ESR

Unit 5: Lasers **(8 hours)**

- General Features and Properties
- Methods of obtaining Population Inversion
- Ray tracing in optical cavities; ABCD law;
- Stability diagram; ray tracing in stable cavity;
- Rate equations for two, three and four level laser systems;
- Spatial and temporal coherence;
- Longitudinal and transverse modes in laser cavities – concepts;
- Q-Switching and Mode Locking

Unit 6: Types of Lasers **(4 hours)**

- Solid-state lasers (Ruby, Nd-YAG)
- Gas Lasers (He-Ne, CO2)
- Semi-conductor lasers
- Ion Lasers (Argon ion and Krypton ion)
- Dye lasers

Unit 7: Laser Spectroscopy **(8 hours)**

- Raman Spectroscopy
- Photoluminiscense process
- Non-linear Optics

Prescribed Textbooks:

1. Jeanne L. McHale, "Molecular Spectroscopy" First Edition, Pearson, 2009.
2. J. Michael Hollas, "Modern Spectroscopy" Fourth Edition, Wiley, 2013.
3. A. K. Ghatak and Thyagarajan, "Optical Electronics", Cambridge University Press, 1989.
4. Amnon Yariv, :Quantum Electronics", John Wiley & sons, 1987.
5. Verdeyan, Laser Electronics, Prentice Hall, 1995.

Other Resources/Reference books:

1. Walter S. Struve, Fundamentals of Molecular Spectroscopy, John Whiley and Sons, 1989.
2. Michael R Muller, "*Fundamentals of Quantum Chemistry: Molecular Spectroscopy and Modern Electronic Structure Computations*", 1st Edition, Springer, 2001.
3. Elaine M. McCash, Colin N. Banwell, "Fundamentals of Molecular Spectroscopy", 5th Edition, Mc-Graw Hill Education, 2013.
4. G. Aruldhas, *Molecular Structure and Spectroscopy, 2nd Edition,* PHI Learning, 2009.
5. J Michael Hollas, *Basic Atomic and Molecular Spectroscopy*, Royal Society of Chemistry, 2002.
6. Straughan, B. P. and Walker, S. : Spectroscopy: (Vols. 1 - 3), Chapman and Hall (1976).
7. Chang, R. : Basic Principles of Spectroscopy, McGraw Hill (1971).
8. Characterization of Materials, E. N. Kaufmann, Wiley (2003).

General Physics Laboratory

Course Code: PAS 413 **Course Type: Core Compulsory**

Course Credit: 2

Course Objectives:

The course is designed to perform experiments and simulations to go hand in hand with the theory courses on Classical Mechanics and Electro-Dynamics , All the experiments shall be based on two techniques, Video Motion Based Analysis using Tracker, Data Acquisition using Expeyes kit. All the simulations shall be performed in Scilab.

Experiments:

Lab 1: Simple Pendulum Experiment for small and large angle oscillations

- Introduction to Video Analysis using Tracker.
- Importance of matching the experimental outcomes with theoretically expected results.
- Extension: to study damped harmonic oscillator
- Simulation of the experiment using xcos in Scilab

Lab 2: Coupled Oscillator Experiment

- Normal mode oscillations
- Transfer of energy between the two oscillators
- Determination of g by varying the height of coupling between the oscillators
- Simulation of the experiment using xcos in Scilab

Lab 3: Double Mass Spring System/Double Pendulum

- Obtaining the frequencies of the system and comparision with the theoretically expected result.
- Simulation using xcos in Scilab

Lab 4: Variable Mass-spring system

- To determine the rate of loss of sand with increasing hole size
- To determine the variation in amplitude w.r.t. to rate of loss of mass, for different hole sizes
- Simulation using xcos

Lab 5: Fourier Analysis using Electrical and Electronic circuits

- Obtain the fourier components and co-efficients of a square wave using a LCR circuit
- Obtain the fourier components and co-efficients using op-amp filter circuits

Lab 6: Verification of Fresnel's Equations

- Production and Analysis of linearly and circularly polarised light
- Angular dependence of reflection and transmission
- To explore Brewster's law and find Brewster angle

Lab 7: Dielectric constant of liquids using Colpitts oscillator

Lab 8: Zeeman Effect

Lab 9: Magnetic Susceptibility of a paramagnetic liquid

Reference: Departmental Lab Manuals.

Modern Physics Laboratory

Course Code: PAS 423 **Course Type : Core Compulsory**
Course Credit: 2

Course objectives:

The course is designed to perform experiments to go hand in hand with the theory courses on Condensed Matter Physics, Nuclear physics and Atomic, Molecular and Laser physics

Experiments:

Lab 1: Four Probe Method

- Measurement of resistivity of a semiconductor by four-probe method at different temperature and determination of band gap.

Lab 2: Hall Effect

- Determination of Hall coefficient of a given semiconductor and estimation of charge carrier concentration.

Lab 3: Experiments using Geiger-Muller Counter

- Characterisation of GM tube
- Nuclear counting statistics

Lab 4: Experiments using Gamma-ray spectrometer

Lab 5: Experiments using Alpha spectrometer

- Prepare the radioactive source using electrolysis for thin film decomposition
- Obtain the alpha spectrum and analyse

Lab 6: Zeeman Effect

- Production and Analysis of linearly and circularly polarised light
- Angular dependence of reflection and transmission
- To explore Brewster's law and find Brewster angle

Lab 7: Michelson Interferometer

Lab 8: Electron Spin Resonance

Lab 9: Laser Beam Parameters

- Determine the wavelength of laser
- Determine the laser beam waist and beam spreading
- Determine the coherence length of laser

Reference: Lab Manuals of CUHP.

Computational Physics

Course Code: PAS 428A **Course Type: Core Compulsory**
Course Credit: 4

Course Contents

Unit 1: Ordinary Differential Equations: (8 hours)

- Euler method, Application to Radioactivity, Air drag and Projectile motion
- Euler-Cromet Method, Application to SHO
- Predictor-corrector method (Heun's) method, Application to Damped Harmonic Osicllator
- Second order Runge-Kutta method, Application to Forced Oscillations
- Study of Panetary motion
- Higher-order Runge-Kutta method; Application to Coupled Oscillations

Unit 2: Partial Differential Equations: (8 hours)

- Finite Difference methods: Elliptic Equations- Laplace equation, solution techniques and boundary conditions;
- Parabolic Equations- Heat Conduction Equation, explicit and implicit methods
- Crank-Nicholson Method; Application to Schrodinger equation.
- Finite Element Method: General approach and applications in One-dimension;
- Application to problems in Electromagnetics.

Unit 3: Random Variables and Random Processes: (4 hours)

- Random variables, several random variables; Statistical averages, function of a random variable, moments, characteristic function, joint moments; Transformation of random variables; Sequences of random variables; central limit theorem (without proof);
- Random processes; Stationarity; Mean, correlation and covariance functions; autocorrelation function and properties , cross-correlation functions; Ergodicity; Power spectral density; Gaussian process and its properties;

Unit 4: Random Processes and Monte-Carlo Methods: (6 hours)

- Random number generation-uniform and non-uniform distributions;
- Monte Carlo Integration- Hit and miss, Sample mean integration,
- Metropolis Method;
- Computer "Experiments" - applications of Monte-Carlo methods to problems in physics;
- Variational Monte-Carlo tecnique: Application to solving for the ground

- state of quantum mechanical systems in 1D and 2D

Unit 5: Fast Fourier Transforms and Spectral Methods: (6 hours)

- Discrete Fourier Transform,
- Fast Fourier Transform,
- Sande Tukey Algorithm
- Pseudospectral technique to solve the Schroedinger equation

Core Open Courses

Mathematical Physics

Course Code: PAS 402 **Course Type: Core Open**
Course Credit: 2

Course Objectives:

The course aims to familiarize students to, Matrices, determinants and linear systems, Vector differential calculus, Complex numbers and functions Complex integration

Course Contents

Unit 1: Matrices and their applications-I **(4 hours)**

- Matrices and their operations, linear transformations, special matrices, orthogonal and unitary matrices.
- System of linear equations, augmented matrix, rank of matrix,
- Gauss elimination and Gauss Jordan methods.
- Linear dependence of vectors and *n*-dimensional space, orthonormal basis and Garm-Schmidt method.

Unit 2: Matrices and their applications-II **(4 hours)**

- Matrix eigenvalues, eigenvectors of a matrix, Cayley-Hamilton theorem.
- Theorems about eigen values and applications.
- Coordinate transformations and matrices. Linear and similarity transformations.
- Diagonalization of matrices.

Unit 3: Complex numbers and functions **(4 hours)**

- Complex numbers and complex plane, Polar form of complex number, roots,
- Derivative and analyticity, Cauchy-Riemann equations,
- Analyticity and Laplace’s equations.
- Complex form of exponential, trigonometric, hyperbolic and logarithmic functions.

Unit 4: Complex integration-I **(4 hours)**

- The line integral in a complex plane, ML inequality, Cauchy’s integral theorem
- Cauchy’s integral formula, n-th order derivatives of analytical function, Cauchy’s inequality
- Power, Taylor, Maclaurin and Laurent series, Radius of convergence
- Singularities and zeros, Zeros of an analytical function.

Unit 5: Complex integration-II **(4 hours)**

- Laurent series and Residue integration method.
- Calculating residues
- Residue theorem.
- Applications of residue theorem to solve integrals in complex plane.

Prescribed Textbooks (Key texts):

1. Mathematical Methods for Physicists by G. Arfken and H.J. Weber , Elsevir Academic Press
2. Mathematical Methods in the Physical Sciences by W.L. Baos, John Wiley & Sons

Other Resources/Reference books:

1. Advanced Engineering Mathematics by Erwin Kreyszic, John Wiley & Sons
2. Explorations in Mathematical Physics: The Concepts Behind an Elegant Language by Don Koks, Springer Science
3. Mathematical Physics by B.S. Rajput, Pragti Prakashan
4. Mathematical Methods in the Physical Sciences by W.L. Baos, John Wiley & Sons
5. Advanced Engineering Mathematics by Peter V. O'Neil, Thomson

Electronic Circuits

Course Code: PAS 405 **Course Type: Core Open**
Credits: 2
Course Objectives:

The course is designed to under the detail of the basics of diode its types, characteristics and applications (diode circuits) like rectifiers, Clipper, Clamper, comparator, sampling gate etc. Integrated circuits as analog system building blocks: including linear and nonlinear analog systems. Integrated circuits: digital system building blocks including adders etc.

Course Contents

Unit 1: Transport Phenomena in Semiconductors (4 hours)

- Generation and recombination of charges
- Diffusion
- The continuity Equation
- Injected Minority charge carrier (low level injection)
- Potential variation with in a graded semiconductor

Unit 2: Junction Diode Characteristics (5 hours)

- Open circuit p-n junction diodes
- p-n junction as rectifier
- Current components in p-n junction diode
- Volt-ampere characteristics and its temperature dependence
- Diode resistance
- Space charge or transition capacitance, varactor diodes.
- Charge control description of diode
- Diffusion capacitance
- Junction diode switching times
- Breakdown diode
- Semiconductor photodiode
- Photovoltaic effect and light emitting diode

Unit 3: Diode Circuits (4 hours)

- Diode as circuit element
- The loade line concept
- piece wise linear diode model
- clipping circuit,
- clipping at two independent levels
- Clampers
- comparator, sampling gate
- rectifiers, and capacitor filter

Unit 4: Integrated Circuits as Analog System Building Blocks

(3 hours)

- Basic Operational Amplifiers
- Differential amplifier and its transfer characteristics
- Frequency response of operational amplifiers

Unit 5: Analog Systems (4 hours)

- Linear Analog System: basic operational amplifier applications, differential dc amplifier, stable ac coupled amplifier, analog integration and differentiation, electronic analog computation, active filters.
- Non-Linear Analog System: comparators, logarithmic amplifiers, wave generators,

Prescribed Textbooks:

1. Integrated Electronics by Jacob Miliman and Cristos Halkias, Tata McGraw-Hill Edition
2. Electronic device and circuit theory by Robert L. Boylestad and Louis Nashelsky, Pearson Education.

Other Resources/Reference books:

1. Operational Amplifiers Design and Applications by Jerald G. Graeme, Gene E. Tobey, Lawrence P. Huelsman, McGraw-Hill.
2. Digital Electronic Principles by A. P. Malvino, Tata McGraw Hill..
3. Electronic Devices and Amplifier Circuits by Steven T. Karris, Orchard Plications

Semiconductor Devices

Course Code: PAS 412 **Course Type: Core Open**

Course Credit: 2

Course Objectives:

Applications in solving problems of interest to physicists. Explore the potential application of semiconducting devices

Course Contents

Unit 1: Semiconductor Materials **(4 Hours)**

- Charge Carriers in Semiconductors
- Dopant Atoms & Energy levels
- The Extrinsic Semiconductors
  - Statics of Donors & Acceptors
  - Charge Neutrality

Unit 2: Carrier Transport in Semiconductors **(6 Hours)**

- Carrier Drift (Drift Current, Mobility, Conductivity)
- Carrier Diffusion (Diffusion Current Density, Total Current Density)
- Graded Impurity Distribution (Induced Electric Field, The Einstein Relation)
- Carrier Generation and Recombination
- Characteristics of Excess Carrier
- Ambipolar Transport

Unit 3: The pn Junction **(4 Hours)**

- Basic Structure of the pn Junction
  - Zero Applied Bias
  - Reverse Applied Bias
  - pn Junction Current
- Small-Signal Model of the pn Junction
- Generation-Recombination Current
- Junction Breakdown

Unit 4: The Bipolar Transistor **(3 Hours)**

- The Bipolar Transistor Action
- Minority Carrier Distribution
- Low Frequency Common-Base Current

Unit 5: Metal-Semiconductor Junction: **(3 Hours)**

- The Schottky Barrier Diode
- Metal-Semiconductor Ohmic Contacts
- Heterojunctions

Prescribed Textbooks:

1. Semiconductor Physics & Devices, D. A. Neamen, Mc Graw Hill (2003).
2. Semiconductor Device Physics and Technology, S.M Sze, Wiley (1985).

Other Resources/Reference books:

1. Introduction to Semiconductor Devices, M. S. Tyagi, John Wiley & Sons.
2. The Physics of Semiconductor Devices, D.A. Eraser, Oxford Physics Series (1986).
3. Semiconconductor Devices: Basic Principles, Jasprit Singh, Wiley (2001).

Computer Simulations in Physics

Course Code: **PAS 414** **Course Type: Core Open**
Course Credit: 2

Lab 1: Superposition of Waves

- Introduction to Scilab
- Fourier Series of square wave, triangle wave and other periodic waveforms

Lab 2: Construction of Wave packet

- using superposition of waves
- using Fourier transform

Lab 3: Solving the Time-Independent Schrodinger Equation using finite differences

- 1-D Finite Square Well potential using worksheet environment and using
- Comparision with analytically expected solutions

Lab 4: Propagator method

- Obtaining the energy eigen values using propagator method
- Finite square well
- Comparision with previous technique

Lab 5: Extension of Propagator method to

- Double Square well
- N-square wells

Lab 6: Matrix Methods

- Obtaining the energy eigen values and wavefunctions for
- Finite sqaure well potential
- Delta function potential

Lab 7: Extension of matrix method to

- Double well potential
- N-well potential

Lab 8: Matrix methods to solve

- Harmonic Oscillator using matrix methods
- Anharmonic Oscillator using matrix methods

Lab 9: Solving the Radial equation for Hydrogen atom using matrix methods

- Infinite Square well potential wavefunctions as basis functions
- Trying other basis functions

Reference: Department Lab Manual

Electronics Lab

Course Code: PAS- 415 **Course Type: Core Open**
Credits: 2

Experiments:

Lab 1: Negative Feedback Amplifiers and Instrumentation Amplifier
Lab 2: Regenerative Feedback System, Astable and Monostable Multivibrator
Lab 3: Integrators and Differentiators

Lab 4: Voltage Controlled Oscillator

Lab 5: Phase Locked Loop

Lab 6: DAC and ADC

Lab 7: Introduction to Arduino kit : Flashing of LED lights

Lab 8: Interactive Traffic Lights

Lab 9: Temperature Alarm

Lab 10: Any interesting project using Arduino kit

References:

1. Learning to Design Analog Systems using Analog System Lab Starter Kit, Dr. K.R.K. Rao and Dr. C.P. Ravikumar, Texas Instruments, India
2. Internet for Arduino

Computational Physics Laboratory

Course Code: **PAS 427** **Course Type: Core Open**

Course Credit: 2

Statistical Mechanics Simulations:

Worksheet based Simulations:

- **Lab 1:** Microstates, Macrostates and Steady-state equllibrium
- **Lab 2:** Ergodic Hypothesis Demonstration

Simulations in Scilab:

- **Lab 3:** Boltzmann Distibution: P(E) vs E
- **Lab 4:** Boltzmann Speed Distribution and Maxwell's velocity distribution
- **Lab 5:** Joule's Expansion and Entropy

Quantum Mechanics Simulations:

- **Lab 6:** Solving the Time-Dependent Schrodinger Equation and obtaining the spreading of Gaussian wavepacket
- **Lab 7:** Studying the Scattering of Gaussian wavepacket
- **Lab 8:** Scattering from a step potential and a barrier potential

General relativity

Course Code: PAS- 506 **Course Type: Core Open**
Course Credit: 2
Course Objectives:

General theory of relativity is presently the accepted theory of classical gravity. It was created by Einstein in 1915 in an endeavor to extend the principles of special relativity for accelerated observers. This theory is considered the greatest scientific creation by any individual since the time of Newton. As you might be aware, general theory of relativity has been applied everywhere with great success, be it in the stars(relativistic astrophysics), the universe (relativistic cosmology) or the GPS in your our mobile phone. A theory with such vast set of applications (and almost a hundred years old), we believe, is a must learn for students. The course is designed to introduce you to the fundamentals of the theory and it's application in understanding the geometry and space time structure of compact massive objects.

Course Contents

Unit 1: Newtonian gravity and special relativity **(2hours)**

- Newton's theory of gravity
- The principle of equivalence.
- Linearity and light

Unit 2: Tensors in the Minkowski space time
(4(hours)

- Inertial coordinates and the Lorentz transformations.
- Four vectors and tensors in the Minkowski space time.
- Tensor algebra.
- Energy- momentum tensors.

Unit 3: Tensors on curved space time **(6 hours)**

- Tensor algebra.
- Covariant derivative and parallel transport.
- Tensor densities and tensor integration Gauss' and Stokes' theorem.
- Time like and null geodesics.
- Curvature tensors: the Riemann and the Ricci tensors.

Unit 4: Einstein's equations **(4 hours)**

- Einstein's tensor and the Einstein equation.
- The Newtonian approximation.
- The Einstein equations with matter and cosmological constant.
- Einstein's equations from an action principle: The action for gravity and it's variation, The action for matter and electromagnetic fields.

Unit 5: Spherical symmetry and compact objects **(4 hours)**

- The Schwarzschild solution.

- Gravitational collapse and black holes: the Erdington-
- Finkelstein and the Kruskal coordinates.
- Particle motion in the Schwarzschild geometry: the perihelion advance.
- Rotating bodies: the Kerr solution.

Prescribed Textbooks:

1. N. M. J. Woodhouse- General relativity, Springer (2000).
2. J. Hartle- Gravity, Pearson, (2000).

Other Resources/Reference books:

3. E. Taylor and J. Wheeler: Spacetime physics, W.H. Freeman (1992).
4. E. Taylor and J. Wheeler: Exploring black holes, Addison Wesley (2000).
5. B. Schutz: A first course on general relativity, Cambridge Univ. press, (2009).
6. A. Einstein: The special and the general theory, Empire books, (2013).
7. R. d'Inverno: Introducing Einstein's relativity, Oxford Univ. press (1992).
8. B. Schutz: Geometrical methods in mathematical physics, Cambridge Univ. press

Accelerator and Reactor Physics

Course Code: PAS 528 **Course Type: Core Open Course**
Credit: 2

Course Objectives:

The course is designed to Review, Introduction: Historical view and main parts,,Types Design and Working of Accelerators and Reactors, Accelerators in CERN: LHC , Applications and Nuclear Safeguards

Course Contents

Unit 1: Accelerators **(3 hours)**

- Historical Developments, Layout and Components of Accelerators
- Electrostatic Accelerators, Linear Accelerators, SLAC
- Phase Stability, Low Energy Circular Accelerators

Unit 2: High Energy Accelerators **(4 hours)**

- Synchro-cyclotron, Proton Synchrotrons
- Colliding Beam Accelerators: Tevatron and Storage Rings
- Accelerators at CERN, Large Hadrons Collider (LHC)

Unit 3: Neutron Physics **(3 hours)**

- Neutron Sources, Absorption and Moderation of Neutrons
- Neutron Reaction and Cross-sections
- Neutron Capture

Unit 4: Nuclear Reactors **(7 hours)**

- Energy and Characteristics of Fission, Nuclear Chain Reaction
- Physics of the Nuclear Reactor and Critical Size of a Reactor
- Types, Design and Working of Fission Reactors
- Characteristics of Fusion, Thermonuclear Reactions, Fusion Reactors, Design of Fusion Power Plant

Unit 5: Applications & Nuclear Safeguards **(3 hours)**

- Indian Accelerators & Reactors, Nuclear Power, Reactor Safety, Domestic and International Nuclear Safeguards and Nuclear Waste Management.

Prescribed Textbooks:

1) D. C. Tayal: Nuclear Physics, Himalaya Publishing House Pvt. Ltd.
2) Kenneth S. Krane : Introductory Nuclear Physics, John Wiley & Sons, 1988.

Other Resources/Reference books:

1. S.Y. Lee: Accelerator Physics, World scientific, 2004.
2. W.M. Stacey: Nuclear Reactor Physics, Wiley-VCH Verlag GmbH & Co.
3. H. Staneley: Principles of Charged Particle Acceleration, John Wiley & Sons.
4. H. Wiedemann: Particle Accelerator Physics I**,** Springer, 1999.

Group Theoretical Physics

Course Code:PAS- 529 **Course Type: Core Open**
Credits: 2
Course Objectives:

Symmetry plays an important role in physics and these symmetry transformation form groups, in this context the study of groups become imperative to understand the basic structure of the theory. To begin with, we will start by introducing group axioms, subgroup, permutation group, cyclic group, conjugate group and conjugacy class etc. Theory of group representation will be discussed in the second part of the course. In the third and last part, continuous groups in the context of particle physics and point groups in the context of crystal structure will be discussed.

Course Contents

Unit 1: Introduction to Groups **(6 hours)**

- Definition of Group: Some simple examples, Group and multiplication table.
- Subsets in a group: Subgroup, cosets, Conjugate element and conjugacy class
- invariant subgroup, Homomorphism of two groups, direct product
- Point groups and cyclic groups, Cayley theorem: application for finding group structure of finite groups of order 3, 4, 5 and 6
- Lagrange theorem, Rearrangement theorem.

Unit 2: Representation Theory-I **(5 hours)**

- Representations: a formal introduction
- irreducible, equivalent, nonequivalent representations
- Unitary representation, Maschke's theorem, Schur's lemmas
- orthonormality and completeness relations of irreducible representation matrices
- orthonormality and completeness relations of irreducible characters.

Unit-3: Representation Theory-II **(5 hours)**

- The regular representation, The direct product representation
- C. G. coefficients, irreducible basis vectors
- character table for group S_4, irreducible representation of Dihedral group D_4
- 3D representation of the group of rotation.

Unit 4: Permutation groups
(6 hours)

- Multiplication of permutations, permutations, cycles, classes in permutation group
- Young pattern, Young tableaux, Young operators
- irreducible representation of S_n
- symmetry groups of crystals, point groups and space groups.

Unit 5: Continuous groups **(8 hours)**

- Lie groups, Adjoint representation of a Lie group

- The rotation group SO(2), Generators of SO(2), Irreducible representation of SO(2)
- Description of the group SO(3), The angle and Axis parameterization, Euler angles
- Irreducible representations of SO(3), homomorphism of SU(2) onto SO(3)
- SU(n) group and particle physics: SU(2), SU(3), and young tableaux.

Prescribed Textbooks:

1. W. K. Tung, Group Theory in Physics, World Scientific publishing Co. Pte. Ltd.
2. Zhong-Qi Ma, Group theory for physicists, World Scientific.
3. H. F. Jones, Groups, Representations and Physics, Institute of Physics Publishing, 1998.

Other Resources/Reference books:

1. S. Sternberg, Group Theory and Physics, Cambridge University Press.
2. Volker Heine, Group Theory in Quantum Mechanics, Pergamon Press Ltd.
3. L. M. Falicov, Group Theory and its Physical Application, University of Chikago Press.

Elective Specialization Courses

Quantum Field Theory

Course Code:PAS 426A **Course Type: Elective Specialization**

Course Credit: 4

Course Objectives:
Quantum field theory is the basis of modern theory of microscopic physics. This course provides us with a set of mathematical rules which when computed for physical processes give highly accurate results. Moreover, the formulation of these quantum field theories provides deep insights towards the mathematical, physical and philosophical foundations of the microscopic world. The plan of this course is to introduce the basics of field quantization. Students will learn the quantum theoretic descriptions of the electromagnetic, the weak and the strong forces and standard electroweak theory.

Course Contents

Unit 1: Theory of classical fields and symmetries **(6 hours)**

- Why quantum field theory, creation and annihilation operators
- relativistic notation and natural units
- Action principal and the Euler- Lagrange equations, Hamiltonian formalism, Noether theorem

Unit 2: Quantisation of free fields **(6 hours)**

- Scalar fields, field and its canonical quantization, ground state and Hamiltonian, Fock space
- Complex scalar fields and propagator
- Dirac fields, Hamiltonian, free particle solutions, projection operators
- Lagrangian, Fourier decomposition and propagators

Unit 3: S-matrix, Cross- sections and decay rates **(8 hours)**

- Evolution operator, S-matrix and Wick's theorem
- Yukawa interaction, fermion scattering, Feynman amplitude and rules
- Decay rates and scattering cross-sections
- Four fermion interaction
- Mandelstam variables

Unit 4: Quantum electrodynamics **(8 hours)**

- Classical electromagnetic fields and quantization problems
- Modified Lagrangian, propagator, Fourier decomposition, Feynman rules for photons
- Local Gauge invariance and it's consequences: U(1), SU(2) and SU(3).
- Interaction Hamiltonian, e-e scattering

Unit 5: Renormalization **(4 hours)**

- Degree of divergence, Specific Example of QED
- Self energy, vacuum polarization, Vertex function
- Regularisation of self energy, modified Coulomb interaction
- Running coupling constant, cancellation of infrared divergences

Unit 6: Non-Abelian gauge theories and Standard electroweak theory (8 hours)

- Spontaneous symmetry breaking, Goldstone bosons, Higgs Mechanism
- Yang-Mills theory of non-Abelian gauge fields
- Interaction of gauge fields
- Feynman rules, colour factors, QCD Lagrangian

- Gauge group, Fermions in theory
- Gauge boson decay
- Scattering processes
- Propagators, global symmetries of the model

Prescribed Text books:

1. A. Lahiri and P.B. Pal- A First Book of Quantum Field Theory 2nd edn., Narosa Pub. (2004).
2. G. Sterman- An Introduction to Quantum Field Theory, Cambridge University Press (1993).

Prescribed Reference books:

1. F. Mandl and G. Shaw- Quantum Field Theory 2nd Edition, Wiley & Sons (2010).
2. Peskin and D. Schroeder- An Introduction to Quantum Field Theory, Levant Books (2005).
3. P. Ramond- Field Theory: A Modern Primer, Westview Press (1995).
4. S. Weinberg- Quantum field theory, Cambridge University Press (1998).

Theory of General relativity

Course Code: PAS- 506 A **Course Type: Elective Specialization**
Course Credit: 4

Course Objectives:

General theory of relativity is presently the accepted theory of classical gravity. It was created by Einstein in 1915 in an endeavor to extend the principles of special relativity for accelerated observers. This theory is considered the greatest scientific creation by any individual since the time of Newton. As you might be aware, general theory of relativity has been applied everywhere with great success, be it in the stars (relativistic astrophysics), the universe (relativistic cosmology) or the GPS in your our mobile phone. A theory with such vast set of applications (and almost a hundred years old), we believe, is a must learn for students. The course is designed to introduce you to the fundamentals of the theory and it's application in understanding the geometry and spacetime structure of compact massive objects.

Course Contents

Unit 1: Newtonian gravityspecial relativity **(5 hours)**

- Basics of special relativity, Newton's theory of gravity,
- The principle of equivalence, Non-inertial frames and non-Euclidean geometry.
- General coordinate transformations and the general covariance of physical laws.

Unit 2: Geometry of curved spacetime **(10 hours)**

- Contravariant and covariant vectors; Tangent vectors and 1-forms;
- Tensors: product, contraction and quotient laws; Wedge product, closed forms;
- Levi-Civita symbol; Tensor densities, the invariant volume element.
- Parallel transport and the affine connection; Covariant derivatives;
- Metric tensor, raising and lowering of indices;
- Christoffel connection on a Riemannian space;
- Geodesics;
- Space-time curvature; Curvature tensor; Commutator and Lie derivative;
- Equation for geodesic deviation; Symmetries of the curvature tensor; Bianchi identities;
- Isometries and Killing vectors.
- Energy- momentum tensors and conservation laws.

Unit 3: Einstein's equations **(10 hours)**

- Einstein's tensor and the Einstein equation,
- The Newtonian approximation,
- The Einstein equations with matter and cosmological constant.
- Einstein's equations from an action principle: (i) The action for gravity and

Unit 4: Exact solutions, compact objects **(10 hours)**

- Stars and black holes

- Static, spherically symmetric space-time; Schwarzschild's exterior solution;
- Motion of perihelion of Mercury; Bending of light; Gravitational red shift. Radar echo delay.
- Schwarzschilds interior solution; Tolman-Oppenheimer-Volkov equation;
- Collapse of stars, formation of white dwarfs, neutron stars and supernovae bursts.
- Black holes: Eddington- Finkelstein, Kruskal-Szekeres coordinate systems and Painleve- Gulstrand coordinates.
- Reissner-Nordstrom metric, Kerr metric; Ergosphere; Kerr-Newman metric.
- General description of horizons: event horizons and Killing horizons.
- Laws of black hole evolution.

Unit 5: Large scale structures and singularity theorems (5 hours)

- The Weyl postulate and the cosmological principle;
- Robertson-Walker metric; Friedman cosmology.
- Early universe.
- Anisotropies, vorticity and shear; Raychaudhuri equation;
- Singularity theorems of Hawking and Penrose .

Prescribed Textbooks:

1. S. Weinberg: Gravitation and Cosmology
2. P.A.M. Dirac: General Theory of Relativity
3. L. Landau and E. M. Lifshitz: Classical theory of fields, Pergamon.

Other Resources/Reference books:

1. J.V. Narlikar: Introduction to Cosmology, Cambridge.
2. J. Hartle- Gravity, Pearson, (2000).
3. N. M. J. Woodhouse- General relativity, Springer (2000).
4. E. Taylor and J. Wheeler: Spacetime physics, W.H. Freeman (1992).
5. E. Taylor and J. Wheeler: Exploring black holes, Addison Wesley (2000).
6. B. Schutz: A first course on general relativity, Cambridge Univ. press, (2009).
    A. Einstein: The special and the general theory, Empire books, (2013)
7. S. Chandrasekhar: An introduction to stellar structure, Cambridge Univ. press.
8. R. d'Inverno: Introducing Einstein's relativity, Oxford Univ. press (1992).
9. B. Schutz: Geometrical methods in mathematical physics, Cambridge Univ. press (1980).
10. C.W. Misner, K.S. Thorne and J.A. Wheeler: Gravitation
11. R.M. Wald: General Theory of Relativity, Chicago university press.

Theoretical Nuclear Physics

Course Code: PAS 527 **Course Type: Elective Specialization**
Credits: 4

Course Objectives:

The course is designed to study the following, Interaction of nuclear radiation like charged particles, neutrons, gamma and positron with matter and how these radiations are detected. Study of decay laws, theory and use in the structure exploration of nuclei. Nuclear reactions, kinematics, reaction cross-sections, different types and theories developed. Nuclear Fission, characteristics and applications. Basic fusion process it characteristics, solar fusion etc.

Course Contents

Unit 1: Interaction of nuclear radiation with matter (10 hours)

- Interaction of charged particles with matter
- Interaction of neutrons with matter: energy loss and energy distribution after collision
- Interaction of gamma radiation with matter: attenuation of gamma rays, Compton Effect, photoelectric effect and pair production.
- Interaction of positron with matter
- Detection of nuclear radiation

Unit 2: Radioactive Decay (10 hours)

- Radioactive decay law, Quantum theory of radiative decays, production and decay of radioactivity, Growth of Daughter activities.
- Alpha decay: energetic, decay constant, hindrance factors, alpha particle spectra
- Fermi theory of β-decay, Electron and positron energy spectra, electron capture decay, parity non conservation in β-decay, nuclear structure information from β-decay.
- Theory of γ-decay and internal conversion and nuclear structure information from γ-decay

Unit 3: Nuclear reactions (12 hours)

- Cross-sections, reciprocity theorem, Elastic scattering and method of partial waves, relationship between differential and scattering amplitude.
- Free particle, turning the potential on, scattering amplitude and elastic scattering cross-section, reaction cross-section.
- Scattering by simple potential, square well potential.
- Theory of resonance: General aspects, logarithmic derivative and cross-section, Breit-Wigner formula, R-Matrix theory.

Unit 4: Nuclear Fission and Fusion (8 hours)

- Fission: Characteristics of Fission, Energy In Fission, Fission and Nuclear Structure, Controlled Fission Reactions, Fission Reactors, Radioactive Fission Products, Fission Explosives.
- Basic fusion processes, characteristics of fusion and solar fusion.

Prescribed Text Books:

1. Introductory Nuclear Physics, K. S. Krane, John Wiley& Sons Ltd
2. An Introduction to Nuclear Physics, W. N. Cottingham, D. A. Greenwood, Cambridge University Pres

Other Resources/Reference books:

1. Fundamentals In Nuclear Physics from Nuclear Structure to Cosmology Jean-Louis Basdevant, James Rich, Michel Spiro, Springer
2. B.R. Martin, Nuclear and Particle Physics, John Wiley& Sons Ltd.
3. R.R. Roy and B.P. Nigam, Nuclear Physics: Theory and experiment, New age International (P) limited, Publishers.

Particle Accelerators, Detectors and Reactors

Course Code: PAS 528 A **Course Type: Elective Specialization**
Credits: 4

Course Objectives:

The course is designed to study the following, Natural and man-made sources of radiation based on the motion of charge particle in electric and magnetic field. Detectors based on ionisation in Gases, semiconductors material and scintillation etc. Finally the physics of nuclear fission based reactors and their different types.

Course Contents

Unit 1: Natural and Man-made Sources of Radiation (7 hours)

- Natural Sources of radiation
- Units of radiation and radiation Protection
- Electrostatic accelerators
- Cyclotrons
- The quest for the highest energy, synchrotrons and colliders
- Linear accelerators
- Secondary beams and applications of accelerators

Unit 2: Detectors based on ionisation in Gases (7 hours)

- Introduction to detectors for subatomic particles
- Ionisation and charge transport in gases
- Ionisation chambers
- Counters with gas amplification
- Applications of counters with gas amplification: proportional counters for X-ray detection, gas counter for the tracking of high energy.

Unit 3: Detectors based on ionisation in semiconductor materials (3 hours)

- The semiconductor junction as detector
- Silicon and Germanium semiconductor detector

Unit 4: Detectors Based Scintillation (6 hours)

- Introduction to Scintillators
- Organic Scintillators
- Inorganic Scintillators
- Photo detectors
- Using Scintillators in the nuclear energy range
- Applications of Scintillators in high-energy physics and medicine

Unit 5: Basics of Nuclear Reactors **(3 hours)**

- Introduction
- The Fission Process
- Basic Components of a Nuclear Reactor

Unit 6: Thermal and Fast Reactors **(7 hours)**

- Natural Uranium Graphite-Moderated (Magnox) Reactors
- Advanced Gas-Cooled Reactors
- Pressurized-Water Reactors
- Boiling- Water Reactors
- Natural Uranium Heavy Water-Moderated and-Cooled Reactors
- Boiling-Water, Graphite- Moderated Direct-Cycle Reactor (RBMK)
- Liquid Metal-Cooled Fast Breeder Reactors

Unit 7: Cooling Reactors **(7 hours)**

- Introduction
- General Features of Reactors Coolant
- Principles of Heat Transfer
- Gaseous Coolants: Air, Carbon Dioxide, Helium, Steam
- Liquid Coolants: Light Water, Heavy Water, Organic Fluids, Molten Salts, liquid Metals
- Boiling Coolants: Water, Liquid Metals

Prescribed Text Books:

1. Experimental Technique in Nuclear and Particle Physics by Stefaan Tavernier, Springer.
2. Introduction to Nuclear Power, Geoffrey F. Hewitt and John G. Collier, Taylor & Francis

Other Resources/References books:

1. Accelerator Physics by S. Y. Lee, World Scientific.
2. Techniques for Nuclear and Particle Physics Experiments: A How-to Approach by William R. Leo, Springer.
3. Nuclear Energy Principles, Practices, and Prospects by David Bodansky, Springer
4. Elemental introduction to Nuclear Reactor Physics by Salomon E.

Neutrino Physics

Course Code: PAS 546A **Course Type: Elective Specialization**
Credits: 4
Course Objectives:

Elementary introduction to neutrino physics, Electroweak part of the Standard model(SM) of particle physics. Status of neutrino within SM. Possible types of Neutrino mass terms. Neutrino oscillations.

Course Contents

Unit 1: Neutrinos: An Introduction **(8 hours)**

- Pauli's hypothesis of neutrino
- Fermi theory of beta decay
- Difference between ν_e and $\overline{\nu}_e$ and solar neutrino detection
- Discovery of parity violation in weak interaction
- Direct measurement of neutrino helicity
- Discovery of weak neutral current and weak gauge boson
- Charge conjugation
- Helicity and Chirality operators

Unit 2: Standard Model of Electroweak interaction **(8 hours)**

- SU(2) Yang-Mills Local Gauge Invariance
- Spontaneous Symmetry Breaking. Higgs Mechanism
- The Standard Model for Quarks
- The Standard Model for Leptons

Unit 3: Neutrino Mass Terms **(8 hours)**

- Dirac mass term
- Majorana mass term
- Dirac and Majorana mass term
- Nautrino mass term in simplest case of two neutrino fields
- Seesaw mechanism of neutrino mass generation

Unit 4: Neutrino Mixing Matrix **(5 hours)**

- Number of phases and angles in matrix U
- CP conservation in the leptonic sector
- Standard parameterization of mixing matrix U
- Models of neutrino masses and mixings

Unit 5: Neutrino Sources **(3 hours)**

- Solar neutrinos: pp, CNO neutrinos, luminosity constraint, Solar neutrino problem (SNP)
- Atmospheric neutrinos and Atmospheric neutrino problem (ANP)
- Geoneutrino, Supernova neutrinos, reactor neutrinos

Unit 6: Neutrino Flavour Oscillation-I **(4 hours)**

- Flavour neutrino states
- Oscillation of flavour neutrinos: Two neutrino case
- Two neutrino oscillation: CP violation in the lepton sector
- Three neutrino oscillation in the leading approximation

Unit 7: Neutrino Flavour Oscillation-II: Vacuum and matter case **(4 hours)**

- Evolution equation of neutrino in matter

- Propagation of neutrino in matter of constant density
- Adiabatic neutrino transition in matter: Mikheye-Smirnov-Wolfenstein (MSW) effect.

Prescribed Textbooks:

1. Introduction to Physics of Massive and Mixed neutrinos, S. Bilenky, Springer.
2. Fundamentals of Neutrino Physics and Astrophysics, C. Guinti and Chung W. Kim, Oxford University Press.

Other Resources/Reference books:

1. Gauge Theory of elementary particle physics, T. Cheng and L. Lee
2. Modern Elementary Particle Physics, G. Kane
3. Introduction to Elementary particles, David Griffiths, Wiley.

Elementary Particles & Interactions

Course Code: PAS 549 **Course Type: Elective Specialization**
Course Credits: **4**

Course Objectives:

An Overview of Elementary particle physics, Symmetry Principles, conservation laws and Quark Model, Feynman Calculus, QED, and Renormalization, QCD, Weak Interactions and Electroweak Standard Model, Physics Beyond the Standard Model

Course Contents

Unit-1: Introduction and Dirac Equation **(5 hours)**

- Historical Introduction of Elementary particles, Classification, Quantum numbers & Conservation laws
- Four Forces, Range of Forces, Yukawa Potential, Zero Range Approximation
- Dirac Equation: High energy units, Antiparticles and Bilinear covariants

Unit-2: Symmetries and Quarks **(5 hours)**

- Symmetry, Group and Conservation laws, Parity, Charge conjugation, Time reversal
- Combining Representations, Young's Tableaux, SU(2), SU(3) groups
- Quark Model

Unit-3: S- Matrix, Wick's Theorem and QED **(10 hours)**

- The S-Matrix expansion, Wick's theorem
- Electrodynamics of spin 0, ½ particles, Lifetimes and cross-sections, The Golden rule, The Feynman rules for a toy theory, Lifetime of the A, Feynman Rules for QED, Inelastic electron and muon scattering
- Loops, Renormalization and Running coupling constants.

Unit-4: QCD and Weak Interactions **(8 hours)**

- Structure of Hadrons, Partons and QCD
- Parity Violation and the V-A Form of the weak current, Interpretation of the Coupling G, Trace theorems, Muon decay, Charged current neutrino-electron scattering, Neutrino-quark scattering, First observation of weak neutral currents, Neutral current, Neutrino-quark scattering
- The Cabibbo Angle, Weak Mixing Angles, CP Violation: The Neutral Kaon System.

Unit-5: Electroweak Interactions, Standard Model and Beyond **(12 hours)**

- Electroweak theory, Lagrangian in particle physics, Weak spin, Gauge invariance, Standard Model Largrangian, U(1) terms, SU(2) terms, Neutral currents, Charged currents, Quark Lagrangian, Fermion gauge boson Lagrangian
- Standard model masses, Spontaneous symmetry breaking, Abelian Higgs mechanism, Higgs mechanism in the Standard Model
- Grand Unified Theories, Supersymmetry, Strings, etc...

Prescribed Textbooks:

1. Halzen, F. and Martin A.D.: Quarks and Leptons, John Wiley & Sons, 1984.
2. Griffiths, D.: Introduction to Elementary particles, John Wiley & Sons.

Other Resources/Reference books:

1. Martin, B.R. and Shaw, G: Particle Physics, John Wiley & Sons Ltd. 2009.
2. A. Lahiri and P.B. Pal: A First book of quantum field theory, 2nd edn, Narosa publ. house.
3. Gordon, Kane, Modern Elementary Particle Physics, Addison-Wesley Pub. Co. Inc. 1987.
4. Donald, H. Perkins: Introduction to High Energy Physics, Cambridge University Press.
5. Khanna, M.P.: Introduction to Particle Physics, PHI Learning Pvt. Ltd., New Delhi 1999.
6. Tayal, D.C.: Nuclear Physics, Himalaya Publishing House Pvt. Ltd.

Molecular Simulations in Material Science

Course Code: PAS-552 **Course Type: Elective Specialization**
Course Credit: 4
Course Objectives:

This course provides an introduction to modelling and simulation approaches in material science. The course will cover systematic introduction to the theory and algorithms used to implement various approaches in solving many body problems in classically and quantum mechanically. The classical part will cover well known molecular dynamics methods and quantum mechanical part will be based upon density functional based approach. This approach is an exciting new idea that allows designing of materials with desired properties from the bottom up approach.

Course Contents

Unit-1: Understanding the real materials (4 hours)

- Real solids and Hamiltonian for electrons in multiatomic system.
- Challenges for obtaining quantum mechanical solution.
- Born Oppenheimer approximation,
- Free electron and independent electron approximations

Unit-2: Schrödinger Equation for a many electron system (6 hours)

- Challenge of electron-electron interaction and Hartree approximation
- Limitations of Hartree approximation and Slater determinant
- Hartree-Fock approximation and deriving Hartree-Fock equations equations: Variational approach,
- Ground state energy, ionization energy and Koopmans theorem. Excited states and transition energy (ignoring relaxation effects).
- Hartree Fock equations and transition energies in closed shell systems.
- Hartree-Fock-Slater and Hartree-Fock-Roothaan methods. Beyond one electron approximation.

Unit-3: Basis sets (8 hours)

- Plane waves, as basis function and their limitations
- Tight binding approximation
- Orthogonal plane wave method (OPW)
- Frozen core approximation and pseudopotential method,
- Cellular method: its successes and failures
- Muffin tin potentials, augmented plane wave method, (APW)
- Linearized augmented plane waves (LAPW).
- Slater type orbitals, Gaussian type orbitals, Numerical basis functions.

Unit-4: Electron gas (4 Hours)

- Basic elements of free electron gas, Jellium Model
- Homogeneous electron gas in Hartree-Fock approximation.
- Fully polarized ferromagnetic electron gas. Wigner crystallization.

- Electronic properties and phase diagram of homogeneous electron gas.

Unit-5: Basics of density functional theory (8 hours)

- Basics of funcaional analysis. Orbital free density functional theory: Thomas Fermi theory.
- Hohenberg Kohn theorems.
- Kohn Sham (KS) equations.
- KS equations in Plane wave form. k-point sampling.
- Exchange and correlation holes, Exchange correlation functional: Local density approximation.
- Gradient correction methods: Generalised gradient approximation (GGA).
- Basic idea of meta-GGA, hyper-GGA. Band structure and density of states of some standard materials.
- DFT as Materials modelling tool. Limitations of density functional theory.

Unit 6: Fundamentals of Molecular dynamics simulations (10 hours)

- Molecular Dynamics Methodology-Force Field,
- Molecular dynamics potentials, force calculation,
- Long Range Forces and cut off radius
- Integrating Algorithms
- Boundary conditions, Periodic Box and Minimum Image Convention, Non Bonded Interaction
- Temperature Control and thermostats in molecular dynamics
- Pressure Control and Barostats in molecular dynamics
- Estimation of Pure Component Properties
- Radial Distribution Function and its significance
- Molecular Dynamics Packages.

Prescribed text books:

1. Solid State Physics, Guiseppe Grosso and Guiseppe Pastori Parravicini, Academic Press.
2. Introduction to Computational Chemistry, Frank Jensen, 2nd edition, John Wiley and Sons Ltd.

Other Resources/Reference books:

1. Solid State Physics, Guiseppe Grosso and Guiseppe Pastori, Academic Press.
2. Solid State Physics, Neil W. Ashcroft and N. David Mermin, Cengage Learning India Pvt Ltd.
3. The Electronic Structure Of Solids, B.R. Coles and A. D. Caplin, Edward Arnold publishers
4. Electronic Structure: Basic Theory And Practical Methods, Richard M. Martin, Cambridge University press
5. Introduction To Computational Physics, T. Pang, Cambridge University press
6. A Bird's-Eye View of Density-Functional Theory, Klaus Capelle, arXiv:cond-mat/0211443 (2006)

Characterization of Materials

Course Code: PAS 613 **Course Type: Elective Specialization**
Course Credit: 4

Course Contents

Unit 1: Structural Characterization:

- General theory of X-ray scattering and diffraction,
- X-ray diffraction and structural analysis, Powder diffraction,
- Calculation of average crystallite size ,
- Additional Contribution for peak broadening, Basic concepts of small angle X-ray scattering and its application in evaluation of shape and size of surface particles.
- Neutron scattering and diffraction with reference to light elements and magnetic structures.

Unit 2: Microscopy Techniques:

- Optical Microscopes, Electron Microscope Basics and Principles,
- Elementary Concepts of Scanning and Scanning Tunneling Microscopic Techniques (SEM, STM),
- Rutherford Back Scattering (RBS),
- Transmission Electron Microscopy (TEM),
- Specimen Preparation, Imaging Modes, Atomic Force Microscope

Unit 3: Spectroscopic Characterization:

- UV and Visible absorption spectroscopy,
- Fourier Transform Infrared (FT-IR)
- Spectroscopy and Raman spectroscopy:
- Basics of nuclear magnetic resonance (NMR) and electron spin resonance (ESR) spectroscopy,
- Mössbauer spectroscopy,
- X-ray photoelectron spectroscopy,
- Electron Energy Loss Spectroscopy (EELS)

Unit 4: Thermal Analysis:

- Differential Thermal Analysis,
- Differential Scanning Calorimetry,
- Thermogravimetric analysis.

Prescribed Textbooks:

1. B.D.Cullity and S.R.Stock, "Elements of X-Ray Diffraction" Third edition, Prentice Hall,NJ , 2001.
2. David B. Williams, C. Barry Carter, " Transmission Electron Microscopy: A Textbook for Materials Science" ,Springer, pub. 2009.
3. Joseph I Goldstein, Dale E Newbury, Patrick Echlin and David C Joy, "Scanning Electron Microscopy and X-Ray Microanalysis", 3rd Edition , 2005.

Other Resources/Reference books:

1. G.W.H. Hohne, W.F. Hemminger, H.-J. Flammersheim , "Differential Scanning Calorimetry", Springer, 2nd rev. a. enlarged ed., 2003
2. Practical Electron Microscopy in Materials Science, J.W. Edington, 1976, 4 volumes reprinted by Tech Books, Herndon, USA.
3. Characterization of Materials (Materials Science and Technology: A Comprehensive Treatment, Vol 2A & 2B, VCH (1992).
4. Semiconductor Material and Device Characterization, 3rd Edition, D. K. Schroder, Wiley-IEEE Press (2006).
5. Materials Characterization Techniques, S Zhang, L. Li and Ashok Kumar, CRC Press (2008).
6. Physical methods for Materials Characterization, P. E. J. Flewitt and R K Wild, IOP Publishing (2003).
7. Characterization of Nanophase materials, Ed. Z L Wang, Willet-VCH (2000).

Elective Open Courses

Nanomaterials & Technology

Course Code: PAS 516 **Course Type: Elective Open**
Course Credit: 2
Course Objectives:

Applications in solving problems of interest to physicists. Explore the potential application of physics at nanoscale regime.

Course Contents

Unit 1: Nanoscale Systems **(8 hours)**

- Nanostructures and Nanoscale Devices
- Quantization in Nanostrctures
- Quantization in Heterojunction Systems (Quantum Well)
- Lateral Confinement (Quantum Wires and Quantum Dots)
- Electronic States in Quantum Wires and Dots
- Magnetic Field Effects in Quantum Confined Systems
- Transmission in Nanostructures
- Tunnelling in Planar Barrier Structures
- Current in Resonant Tunnelling Diodes
- Landauer Formula &The Multi-channel Case

Unit 2: Synthesis of Nanomaterials **(6 hours)**

- Top-down and Bottom-up Approach
  - ➢ Zero-dimensional nanostructures (nanoparticles)
  - ➢ One-dimensional nanostructures (nanowires)
  - ➢ Two-dimensional nanostructures (thin films)
  - ➢ Special nanomaterials (fullerene, carbon nanotube, graphene)
- Physical Vapour Deposition (PVD)
  - ➢ Pulsed Laser Deposition
  - ➢ Thermal Evaporation
  - ➢ E-beam Evaporation
  - ➢ DC & RF Sputtering
  - ➢ Molecular Beam Epitaxy (MBE)
- Chemical vapour deposition (CVD)
- Lithography
  - ➢ Photolithography
  - ➢ Electron Beam Lithography (EBL)
  - ➢ Focussed Ion Beam

Unit 3: Characterization of Nanomaterials **(6 hours)**

- X-Ray Diffraction
- Optical Microscopy

- Electron Microscopy
    - Scanning Electron Microscopy
    - Transmission Electron Microscopy
- Scanning Probe Microscopy
    - Atomic Force Microscopy
    - Scanning Tunnelling Microscopy

Prescribed Textbooks (Key texts):

1. Transport in Nanostructures, D. K. Ferry, Cambridge University Press (2009).
2. Principals of Nano-optics, L. Novotny and B. Hecht, Cambridge University Press (2006).

Other Resources/Reference books:

1. Quantum Transport: Atom to Transistor, S. Datta, Cambridge University Press (2005).
2. Nanostructures & Nanomaterials, G. Cao, World Scientific (2015).
3. The Science and Engineering of Microelectronic Fabrication, S. A. Cambell, OUP (2001).
4. E. N. Kaufmann, Characterization of Materials, Wiley (2003).

Opto-electronics

Course Code: PAS 518 **Course Type: Elective Open**
Course Credit: 2
Course Objectives:

Applications in solving problems of interest to physicists. Explore the potential application of opto-electronic devices.

Course Contents

Unit 1: Electronic Properties of Semiconductors (4 Hours)

- Modification of Band Structure
  - Modification of Band Structure by Alloying
  - Band Structure of Hetero-structures
- Intrinsic Carrier Concentration
- Defects in Semiconductors
- Doping in Semiconductors

Unit 2: Optical Properties of Semiconductors (4 Hours)

- Transport Properties of Semiconductors
- Carrier Transport by Diffusion
- Optical Properties of Semiconductors
  - Charge Injection and Quasi-Fermi Levels
  - Charge Injection and Radiative Recombination
  - Charge Injection and Non-Radiative Effects
- Modulation of Optical Properties

Unit 3: Light Detection (4 Hours)

- Optical Absorption
  - Photocurrent in a p-n Diode
  - The p-i-n Photodetection
- The Avalanche Photodetector
- The Phototransistor
- Metal-Semiconductor Detectors

Unit 4: Light Emitting Diode (4 Hours)

- Material Systems for LED
  - Operation of The LED
  - External Quantum Efficiency
- Advanced LED Structures
- LED Performance Issues
- Application of LED

Unit 5: The Laser Diode **(4 Hours)**

- Spontaneous and Stimulated Emission
  - The Laser Structure
  - The Laser Below and Above Threshold
- The Time Response of Laser
- Semiconductor Laser Design
- Advanced Structures

Prescribed Textbooks (Key texts):

1. Optoelectronics: An Introduction To Materials And Devices, J. Singh, Mc Graw Hill (2014).
2. Electronic And Optoelectronic Properties of Semiconductors, J. Singh, Cambridge University Press (2003).

Other Resources/References books:

1. Semiconductor Physics & Devices, D. A. Neamen, Mc Graw Hill (2003).
2. Semiconductor Device Physics and Technology, S.M Sze, Wiley (1985).
3. Introduction to Semiconductor Devices, M. S. Tyagi, John Wiley & Sons.
4. Semiconconductor Devices: Basic Principles, Jasprit Singh, Wiley (2001).

Cosmology

Course Code: PAS- 539 **Course Type: Elective Open**
Course Credit: 2
Course Objectives:

You have studied physics at various length scales, from the scale of a nucleus to a few light years (as for example in the solar system). Cosmology goes further beyond. It is the study of the large scale structure of the universe at length scales extending to billions of light years. The questions we ask in this branch of science are the following. How did the universe form ? When did it have it's beginning ? Why did it had the beginning in the way it did ? How do galaxies form ? When did the first elements like the hydrogen and helium form ? ... . The study of these questions needs an understanding of gravity (as it governs the dynamics at large scales) and hence general relativity, which is a theory of gravity, is an essential tool (cosmology is also called relativistic cosmology for this reason). Moreover, we shall also need a basic understanding of modern particle physics (which we shall gather along the way). We shall learn how cosmologists have gathered data and how relativists have interpreted them through their theories. We shall also learn about the cosmic microwave background radiation (CMB) and how they have led to the conclusion that our universe had a beginning and is now expanding in an accelerated mode. The aim of this course is to provide you the tools for a further study in cosmological physics.

Course Content

Unit 1: Tensors and their algebra (3 hours)

- Vectors and their transformation laws.
- Covariant and contravariant tensors.
- Transformation properties of tensors.
- Levi-Civita and Kronecker delta, tensor densities.

Unit 2: Tensor calculas (4 hours)

- Differentiation of tensors.
- Christoffel symbol and transformation properties.
- Covariant derivative, Concept of parallel transport.
- Geodesics and stationary property.
- Gauss' and Stokes' theorems.

Unit 3: Tensors on curved spacetime (3 hours)

- The Riemann and Ricci tensors, Ricci scalar.

- The Bianchi identities.
- Properties of the curvature tensors.

Unit 4: Einstein's equations **(4 hours)**

- Einstein's tensor and the Einstein equation.
- The Newtonian approximation
- The Einstein equations with matter and cosmological constant.
- Einstein's equations from an action principle:
  - The action for gravity and it's variation.
  - The action for matter and electromagnetic fields.

Unit 5: Cosmology **(6 hours)**

- The Weyl postulate and the cosmological principle.
- The Friedmann- Robertson- Walker spacetime
- Kinematics of FRW spacetime, redshifts, luminosity distance.
- Dynamics of FRW spacetime.
- Thermal history of the universe, the first three minutes.
- The present scenario: what we have learnt from the CMB spectrum.

Prescribed Textbooks:

1. P. A. M. Dirac: General relativity, Princeton Univ. Press.
2. S. Weinberg: General relativity and cosmology, Wiley .

Other Resources/Reference Books:

1. J. V. Narlikar: Cosmology, Cambridge Univ. Press.
2. S. Weinberg: Cosmology, Oxford Univ. Press.
3. S. Weinberg: The first three minutes, Basis books.

Modeling and Simulation

Course Code: CSI 411 **Course Type: Elective Open**
Course Credit: 2
Course Objectives:

To introduce students to, Electronic structure calculations using Free Open Source Software (FOSS) Elk, Molecular simulations using FOSS Games

Lab 1: Ground State energy calculations for single atom crystals

- Aluminium in Simple Cubic, BCC and FCC structures

Lab 2: Ground State energy calculation for various elements in diamond structure

- Silicon
- Germanium
- Carbon

Lab 3: Ground state energy calculation for determining the HCP structure

Lab 4: Density of States and Band Structure calculations

- Si, Ge, GaAs, ...

Lab 5: Magnetic properties of simple elements like Fe, Co, Ni,etc

Lab 6: Study of Diatomic molecules using Gamess

- Determination of potential energy curve as a function of bond distance for various diatomic molecules like H2, HCl, etc.
- Obtain the equilibrium bond length, vibrational frequencies and bond strength for each of the molecules.

Lab 7: Study of tri-atomic molecules using Gamess

- Determination of potential energy curve as a function of bond distance and bond angle for triatomic molecules CO2 and H2O
- Obtain the equilibrium bond length, vibrational frequencies and bond strength for each of the molecules.

Lab 8: Study of NH_3 and CH_4 molecules using Gamess

- Determination of potential energy curve as a function of bond distance for various diatomic molecules like H2, Hcl, etc.
- Obtain the equilibrium bond length, vibrational frequencies and bond strength for each of the molecules.

Unitary Symmetry in Quantum Physics

Course Code: PAS 545 **Course Type: Elective Open**
Credits: 2
Course Objectives:

To study the role of symmetry in various aspects of quantum mechanics. How symmetry leads to conserved quantities (Noether theorem). Discrete symmetries, symmetries of the Schrodinger equation, symmetry and degeneracy of states will be discussed. Rotation symmetry, angular momentum and SO(3) group. Symmetries of the Dirac equation. Special unitary SU(2) and SU(3) symmetry and their relation with particle physics.

Course Content

Unit-1: Symmetries and Conservation Laws **(4 hours)**

- Symmetries in Classical Physics
- Symmetries and their physical meaning-Noether Theorem
- Time invariant equations of motion
- Unitary translational operator
- Symmetry and degeneracy of states
- Discrete symmetries

Unit 2: Angular momentum and the Group SO(3) **(4 hours)**

- Wigner theorem
- Rotations in Euclidian space
- Isotropy of Space
- Infinitesimal and finite rotations
- An isomorphism of the rotation group

Unit 3: Symmetries and Further Properties of the Dirac Equation-I **(4 hours)**

- Active and Passive Transformations,
- Transformations of Vectors
- Invariance and Conservation Laws
- The General Transformation
- Rotations
- Translations

Unit 4: Symmetries and Further Properties of the Dirac Equation-II **(4 hours)**

- Spatial Reflection (Parity Transformation)
- Charge Conjugation
- Time Reversal (Motion Reversal)
- Reversal of Motion in Classical Physics
- Time Reversal in Quantum Mechanics
- Time-Reversal Invariance of the Dirac Equation
- Racah Time Reflection, Helicity, Zero-Mass Fermions

Unit 5: The SU(2) and SU(3) Symmetry **(4 hours)**

- Group U(n) and SU(n)
- Generators of U(n) and SU(n)
- Linear independence of the generators
- Lie algebra of SU(2) group, SU(3) group
- The generators of SU(3)

- Linear independence of the generators

Prescribed Textbooks:

1. Walter Greiner and Berndt Muller, Quantum Mechanics Symmetries, Springer
2. H. F. Jones, Groups, Representations and Physics, 2nd edition, Institute of Physics Publishing
3. Franz Schwabl, Advanced Quantum Mechanics, Springer

Other Resources/References books:

1. M. Chaichian and R. Hagedorn, Symmetries in Quantum Mechanics, Institute of Physics Publishing.
2. Volker Heine, Group Theory in Quantum Mechanics, Pergamon Press.

Skill Development Courses

Scientific Writing and Presentation

Course Code:PAS 427A **Course: Skill Development**
Course Credit: 2
Course Objectives:

The course is designed to , prepare scientific papers and presentations. These are introduced in Tutorial sessions; effectively use Latex for creating scientific documents and beamer presentations. These are in lab session.

Course Contents

1. **Structure of a Scientific Paper**

- How to read a Scientific Paper
- How to write a Scientific Paper
- Preparation of Tables and Graphs
- Discussion of Results
- Writing an Abstract and choosing a Title
- The way to write a good Introduction
- All about referencing and Bibliography
- Putting it all together: Journal Paper, Research report, Thesis, Book

2. Art of making Presentations

- The DOs and DON'Ts of a Good Presentation
- The Structure of a good presentation
- Tips for making good Oral Presentations

Lab Sessions:

Lab 1: Introduction to Latex

- Creating an artile with title, author and date and running it to otbain the output

Lab 2: Important parts of a scientific paper

- Structure the content as Abstract, sections, sub-sections and the use of list environments, text formatting and page setting

Lab 3: Generating tables of different styles

- Create tables with multiple columns and multiple rows

Lab 4: Inserting different types of graphs and pictures in different ways and sizes

- Understand the graphics environment by inserting differnt types and sizes of graphs

Lab 5: Typesetting equations of varying complexity

- single line equations and multiple line equations using tabular environment

Lab 6: Referencing and Bibliography

- Different styles of referencing used in various journals and how to prepare the bibtex file appropriately

Lab 7: Preparing reports and book

- How to cross reference figures, tables, equations and references and create list of figures and table of contents

Lab 8: How to use Beamer in Latex for creating presentations

- Creating Title Slide
- Outline of Presentation
- Making Bullets, Enumeration, etc
- Creating blocks
- Splitting the slide into multiple columns

Reference: Departmental Lab Manual

Science of Yoga

Course Code: PAS 556 **Course: Skill Development**
Course Credits: 2
Techniques to be learnt:

- UpaYoga: Simple preparatory exercises for Suryanamaskar
- Suryanamaskar
- Yoga namaskar
- Few Asanas : Vajrasana, Bhujnagasana, Sarvangasana
- Pranayama : Bastrika, Anulom Vilom, Bramari, Udgita and Pranayam
- Mudras
- Five Tibeten Practices
- A Few Prayers: Gayatri Mantra, Gita Slokas and Shanti mantras

Prescribed Textbooks:

1. B.K.S. Iyengar, "**Light on Yoga**", Thorsons, 2006 edition
2. Thich Naht Hanh, **"Silence"**, Rider, 2015
3. Sri Rangarajan Video on "Dinacharya"
4. Sadhguru, "**Inner Engineering: A Yogi's Guide to Joy**" Penguin Publisher, 2016
5. Sri Sri Ravishankar, "**Patnajali Yoga Sutras**", Sri Sri Publicaitons Trust, 2012
6. Baba Ramdev Video on "Pranyaama"
7. Dr. Renu Mahatani, "**Power of Pranayama**", Jaico, 2017

Human-Making Courses

History & Philosophy of Science

Course Code: PAS 417A **Course Type: Human Making**
Credits: 02

Course Objectives:

Given the nature of Foundational Course and learners from diverse background, the course is designed to provide an overview of the course to the students i.e. the introduction of eastern philosophical thoughts leading to the evolution of modern scientific paradigm. It will start with the Indian tradition of Science, philosophical thoughts and quest for understanding nature starting from Vedic era, through Greeks and Arabs to the European lead modern science. Finally, the connection between the Indian thought and modern science is also discussed. It is believed that after completion of this course the students will get a holistic insight into the understanding of nature.

Course Contents

Unit 1: Indian Tradition of Science **(6 hours)**

- Indian efforts for understanding nature and the ultimate reality since the ancient times- starting from the Vedic era to the modern times,
- Science in the ancient texts, Biology, Chemistry, Mathematics and Astronomy, nomenclatures, Scientific Literature,
- Life sketches of ancient Indian scholars,
- Indian schools of thoughts on understanding the origin and evolution of nature and force behind, Kal-Ganana,
- Historical damage to the science and scientific temper, Imprints of science in the Indian social setup i.e. Daily routine, Life style, Festivals and Rituals, Quotes by various researchers.

Unit 2: Nyaya and Vaisheshik Schools of Indian Thought **(4 hours)**

- Nine main Indian Schools of Thoughts,
- The Logics of Nyaya to Understand the Nature and its Dynamism;
- Atomic Theory- Concepts of Atom, Molecule and Mind in Pluralistic tradition of Vaisheshik,
- Basic elements, Motion and Action in Space and Time.

Unit 3: Western Ancient Schools of Thought **(3 hours)**

- Life sketches and contributions of Scientists and Philosophers,
- Before the Greeks (Pre-history-600 BCE),
- Ancient Greek Science (600 BCE – 300 BCE).

Unit 4: Evolution of Modern Science **(5 hours)**

- Period of Stagnancy,
- Scientific Revolution and enlightenment,
- Modern understanding of Life and Universe.

Unit 5: Parallel between Indian Thought and Modern Science **(2 hours)**

- The connection between the Indian thought and Modern Science,
- The Unity of all things,
- Beyond the world of opposites,

- Space-Time, The Dynamic Universe,
- Emptiness and Form,
- The Cosmic dance, Patterns of change and Interpenetration.

Prescribed Textbooks:

1. S.C. Chatterjee and D.M. Dutta, An Introduction to Indian Philosophy, Calcutta University Press (1948).
2. Thomas L. Isenhour, The Evolution of Modern Science, e-book at bookboon.com (2013).
3. Fritzoff Capra, Tao of Physics, Shambhala Pub. Inc.1975.

Other Recourses/Reference books:

1. Keshav Dev Verma, Vedic Physics, Motilal Banarsidass Publishers (2012).
2. P.T. Raju, The Philosophical Tradition in India Motilal Banarsidass Publishers (1992).
3. M. Curd, J.A. Cover and C. Pincock, Philosophy of Science, WW Norton & Co. London 2013.
4. Thomas S. Kuhn, The Structure of Scientific Revolution, the Univ. of Chicago Press, Chicago, 1970.

Science of Yoga

Course Code: PAS 556 **Course: Human Making**
Course Credits: 2

Unit 1: Theoretical Aspects of Yoga (4 hours)
- Origin of Yoga and its brief Development
- Meaning of Yoga and its importance
- Yoga as a Science of Art (Yoga Philosophy)
- Meaning of Meditation and its types and principles

Unit 2: Philosophy of Yoga **(4 hours)**

- Classification of Yoga/ Types of Yoga
- Hatha Yoga, Raja Yoga, Bhakti Yoga, Gyan Yoga, Karma Yoga
- Ashtanga Yoga

Unit 3: Physical Aspects of Yoga **(4 hours)**

- Principles of Yogic Practices
- Meaning of Asana, its types and principles
- Meaning of Pranayama, its types and principles
- Meaning of Kriya, its types and principles

Unit 4: Mental Aspects of Yoga **(4 hours)**

- Yogic therapies and modern concept of yoga
- Meaning and importance of Prayer
- Psychology of Mantras
- Different mudras during Prayers

Unit 5: Anatomy and Physiology for Yogic practices (**4 hours)**

- Introduction to human body and its systems
- Definition of Anatomy and Physiology and importance of yogic practices
- Respiratory, Digestive, Endocrine, Nervous and Circulatory Systems
- Effect of Asanas on various systems

Prescribed Textbooks:

1. B.K.S. Iyengar, “Light on Yoga”, Thorsons, 2006 edition
2. Thich Naht Hanh, “Silence”, Rider, 2015
3. Sri Rangarajan Video on “Dinacharya”
4. Sadhguru, “Inner Engineering: A Yogi's Guide to Joy” Penguin Publisher, 2016
5.

Other Recourses/Reference books:

1. Sri Sri Ravishankar, “Patnajali Yoga Sutras”, Sri Sri Publicaitons Trust, 2012

2. Baba Ramdev Video on "Pranyaama"
3. Dr. Renu Mahatani, "Power of Pranayama", Jaico, 2017
4. Nicolai Bachman, "the Path of the YOGA SUTRAS" Jaico, 2016
5. Anodea Judith, "Chakra Yoga", Jaico, 2017.